RLC and AL-FEC @ IETF: when codes meet transport protocols and practical aspects

Vincent Roca

RLC and AL-FEC @ IETF: when codes meet transport protocols and practical aspects

Vincent Roca, Inria, France

Algebraic approaches to storage and network coding

COST IC1104 meeting

Feb. 7th, 2014, Barcelona

Goals

- focus on **AL-FEC** (all kinds, RLC included) codes for the **erasure channel** and their use in IETF standards

- I'll discuss
  - the key **IETF/IRTF Working Groups**
    - RMT, FECFRAME, DTNRG, NWCRG
  - how is **AL-FEC standardization** addressed at IETF?
    - on the importance of signaling
  - focus on **NetWork Coding (NWCRG)** IRTF activities
    - Tetrys on-the-fly coding
    - structured RLC

A quick survey of related IETF/ IRTF working groups

About IETF

- Internet **Engineering** Task Force http://ietf.org/
  - the place where Internet technology is standardized
    - **TCP/IP and much more…**
    - **historically focusing on protocols, but now embraces FEC**
      - they play a major role in recent communication systems!
  - open to everybody
    - **no fee, open discussion lists**
    - **open specifications (Internet-Drafts and RFCs)**
  - “Internet” is the target use-case
    - **later IETF’s technology is often instantiated by other SDOs (3GPP, DVB, OMA, ISDB, …)**

IETF motto: “we believe in rough consensus and working code”

About IETF (con't)

- about IPR (Intellectual Property Rights, i.e. patents)
  - any IETF/IRTF contributor has to disclose any IPR he/she is "reasonably aware of"
    - **you may be one of the inventors…**
    - **it may be one of your colleagues…**
    - **or anybody else if there is a good reason for you to be aware of the existence of the patent**
  - IETF/IRTF takes no position WRT IPR's validity or scope
    - **it only provides a registry: https://datatracker.ietf.org/ipr/**
  - but WGS are authorized to take it into consideration
  - to know more: https://www.ietf.org/ipr/policy.html

About IETF… (cont')

- two working groups primarily concerned by AL-FEC
  - **RMT** (reliable multicast transport) WG http://tools.ietf.org/wg/rmt/ (1999 - 2013)
    - **AL-FEC and protocols for reliable object distribution to multiple receivers simultaneously**
    - **standardized AL-FEC:**
      - Raptor, RaptorQ, LDPC-Staircase, Reed-Solomon
      - No-code (the most useful one ☺)
    - **AL-FEC and FLUTE/ALC are now widely deployed…**

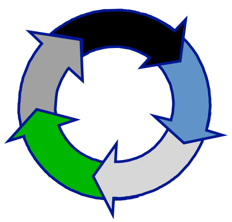
Example: ISDB-Tmm (NOTTV), Japan
Relies on FLUTE/ALC and LDPC-Staircase

Sports program received on a mobile phone

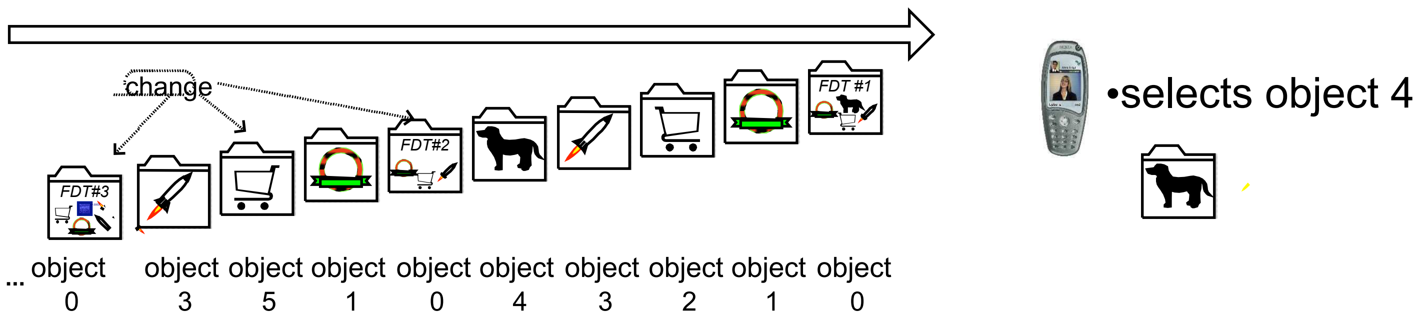
News program on a smart phone

About IETF… (cont')

- example: FLUTE/ALC
  - unidirectional communication (no feedback)
  - massively scalable, from 0 to billions of receivers
  - transmits files (ALC) and metadata (FLUTE)
  - reliability achieved thanks to:
    - the use of AL-FEC
    - the carousel approach (several tx loops)



carrousel (dynamic)
FLUTE/ALC + AL-FEC



About IETF… (cont')

- **FECFRAME** (FEC Framework) WG http://tools.ietf.org/wg/fecframe/ (2006 - 2013)
  - **AL-FEC and protocols for streaming applications**
    - typically RTP/UDP flows
  - **standardized AL-FEC:**
    - Raptor, RaptorQ, LDPC-Staircase, Reed-Solomon, 1D/2D parity
  - **limited deployments so far… but things may evolve**

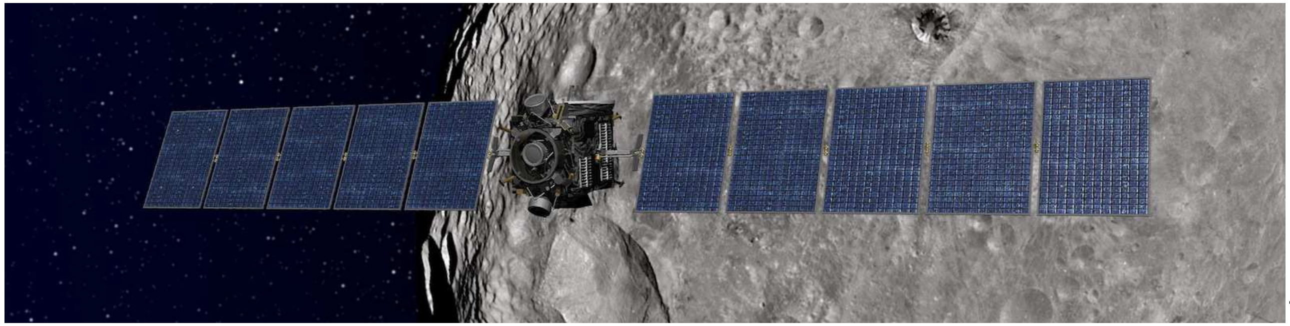
About IRTF

You said I**E**TF or I**R**TF?

- Internet **Research** Task Force http://irtf.org/
  - complements the IETF
    - **focuses on research more than engineering aspects**
    - **it can be the first step before launching an IETF WG**
  - IETF: 125 WGs in 8 areas
  - IRTF: only 9 WGs (!)

About IRTF… (cont')

- two working groups primarily concerned by AL-FEC
  - NWCRG (NetWork Coding) RG http://irtf.org/nwcrg
    (brand new WG, launched on Nov. 2013)
    - **RLC and protocols for network coding**
    - **more to come…**
  - DTNRG (Delay Tolerant Networks) RG http://irtf.org/dtnrg
    (2002 – now)
    - **RLC and protocols for Delay Tolerant Networks (DTN)**
      - ex: space communications
    - **includes an RLC proposal for improved robustness**



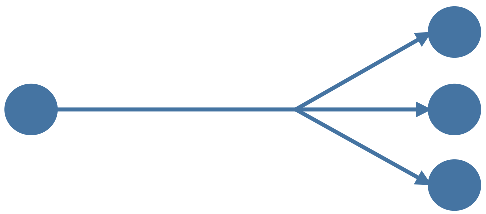
Different transm. models according to WG

end-to-end

RMT

FECFRAME

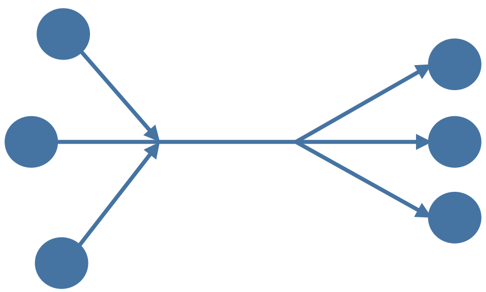
unicast



RMT

FECFRAME

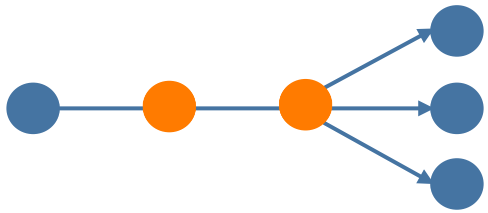
multicast 1 ⇒ n



RMT

multicast m ⇒ n

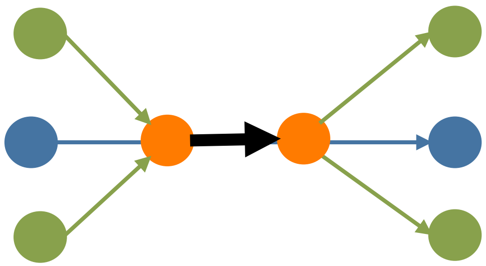
in-network encoding



DTNRG

NWCRG

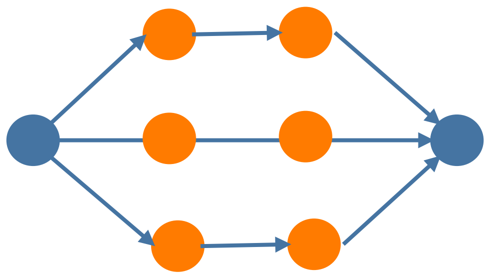
uni/multicast, intra-flow enc.



FECFRAME (middlebox)

NWCRG

uni/multicast, inter-flow enc.



NWCRG

multi-path transfer

How is FEC standardization addressed in IETF?

Situation

- focus on the **erasure channel** only
    - **we're at IETF**
    - **we observe losses, not transmission errors**
    - **causes: router congestion, bad reception conditions (wireless), intermittent connectivity, etc.**
- focus on **"higher" layers**
    - **we're at IETF**
    - **they are called Application-Level FEC, but they are found:**
        - within the **application**
        - within the **transport** layer (e.g. between RTP/UDP for streaming, in FLUTE/ALC for filecasting)
        - within the **MAC** layer (e.g., in DVB-H/MPE-FEC, or in DVB-SH/MPE-IFEC)
        - NB: not sure for routing layer: AL-FEC maybe not? NC maybe?
    - **a direct consequence: everything is done in software**

Situation… (cont')

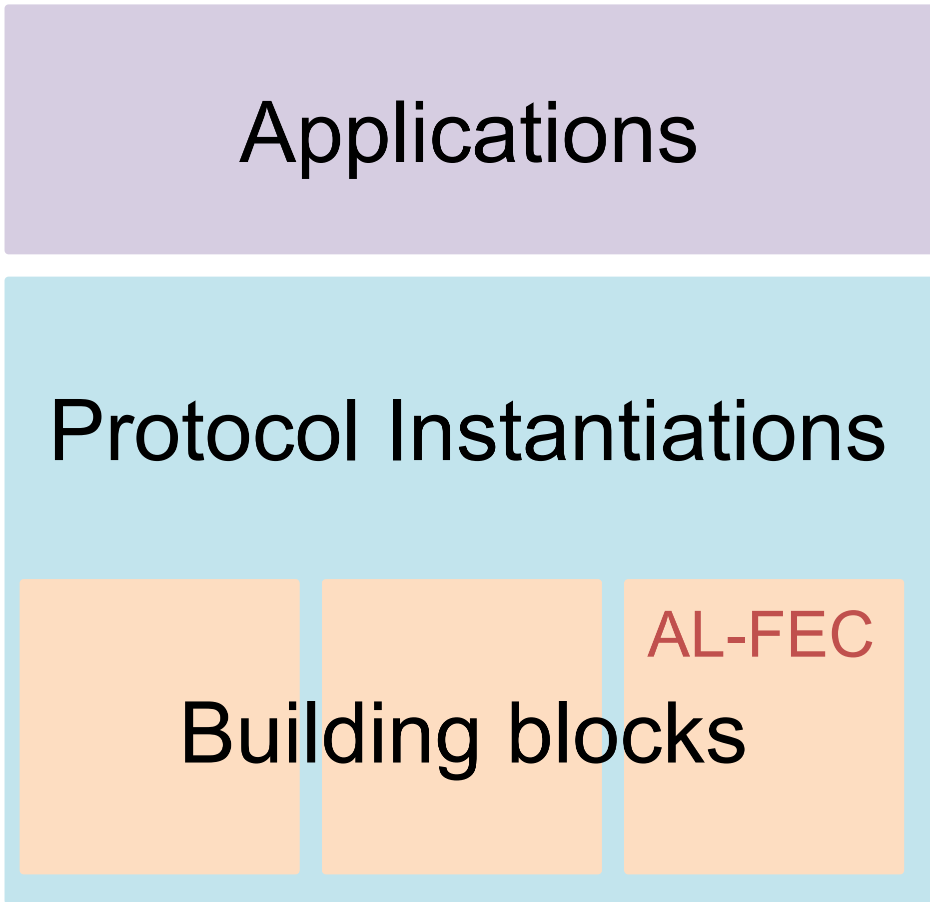
- must accommodate wide variety of **different needs**
  - from **small blocks** (k=10s) to **large blocks** (k=10,000s)
    - **e.g. filecasting as in FLUTE/ALC requires large k values**
      - encoding a very large object with Reed-Solomon over GF(2^8) is quickly limited by the "coupon collector problem"
  - small rate codes are sometimes useful, but **CR ≥ 2/3 is sufficient** most of the time, even in "digital fountain" applications like FLUTE/ALC
  - code parameters (n; k) are determined **dynamically**
    - **code creation time is critical**
      - e.g., no time to apply complex code optimization technics
      - Vandermonde matrix creation for Reed-Solomon is penalizing

Situation… (cont')

- AL-FEC is a small component of a much larger system
  - should be standardized independently
  - should be reusable across different protocols

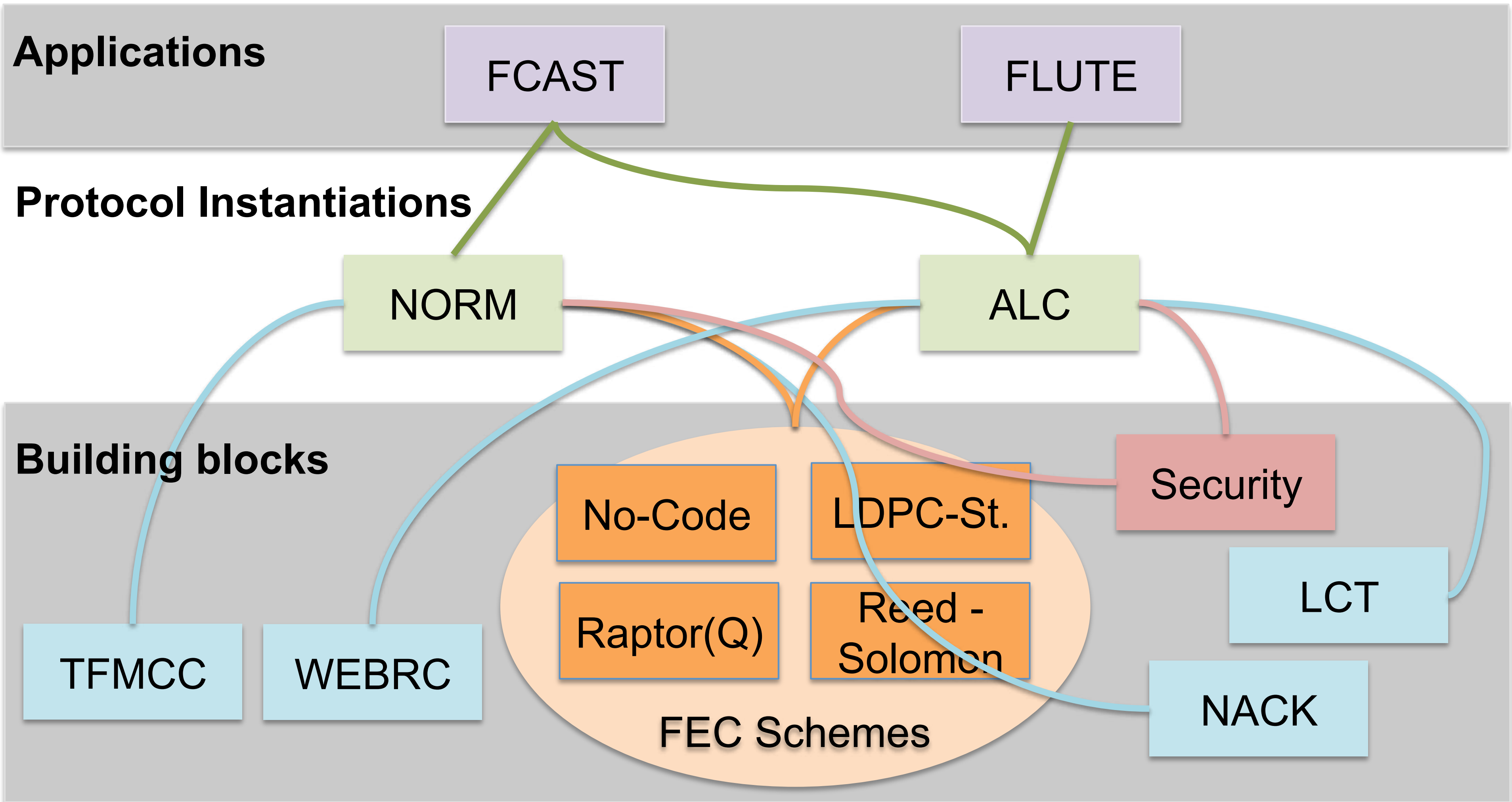
Principle 1: “divide to conquer”

- define applications on top of protocols
  - if meaningful
  - offers specialization
- assemble BBs and create protocol inst.
  - protocol = { building blocks, specialized if needed }
  - working solution
- “building block” (BB) approach
  - focused and reusable components



Principle 1: "divide to conquer"… (cont')

- ex. RMT http://www.ietf.org/proceedings/88/slides/slides-88-nwcrg-1.pdf



Principle 2: "specify FEC Schemes"

- the case of **fully-specified** FEC schemes

  (the general case…)

FEC Scheme

=

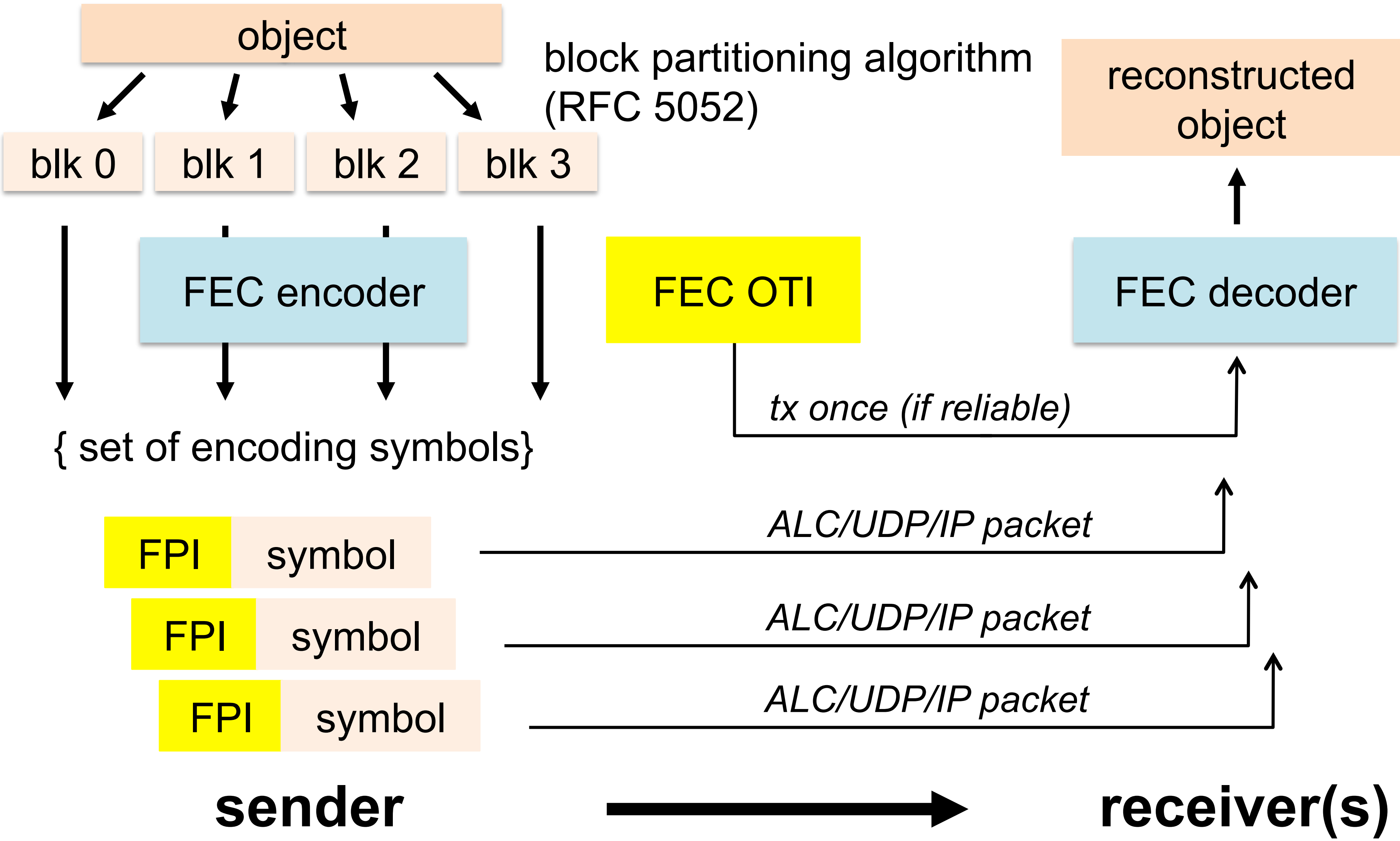
{identifier + code specifications + signaling }

- each scheme is uniquely **identified** (IANA registry)
  - FEC Encoding ID   ex. Reed-Solomon is 5 for RMT
- all the **code details** are specified non ambiguously
  - interoperability is a MUST
- signaling enables encoder/decoder **synchronization**, for a given object transfer

Principle 2: “specify FEC Schemes” (cont’)

- more details on signaling…
  - some information is **sent once (reliably) per object transfer**
    - **FEC Object Transmission Information (FEC OTI)**
    - **info. for the object**
      - object length, parameters to partition it into blocks (if too large), symbol size
    - **info. for the FEC codec**
      - internal parameters, code rate (if needed)
  - some information is **sent in each packet**
    - **FEC Payload ID (FPI)**
    - **which symbol(s) does the packet contain?**
    - **e.g. LDPC-Staircase ([RFC 5170](RFC 5170))**

Principle 2: “specify FEC Schemes” (cont’)



Principle 2: "specify FEC Schemes" (cont')

- to know more about FEC Building Blocks
  - RMT ⇒ RFC 5052 http://tools.ietf.org/html/rfc5052
  - FECFRAME ⇒ RFC 6363 http://tools.ietf.org/html/rfc6363
  - in any case, signaling is essential to FEC

Focus on some NetWork Coding IRTF RG activities (nwcrg)

A key aspect: what type of FEC code?

- NC use-cases ask for more flexibility than RMT/ FECFRAME do
    - **re-encoding of coded packets, distributed encoding, sliding window encoding, etc.**
    - **blocks are really an issue in that case**

- but not necessarily all potential use-cases
  - end-to-end NC still makes sense!
    - **see Tetrys and Structured RLC**

What type of FEC code… (cont')

- block encoding

RMT FECFRAME

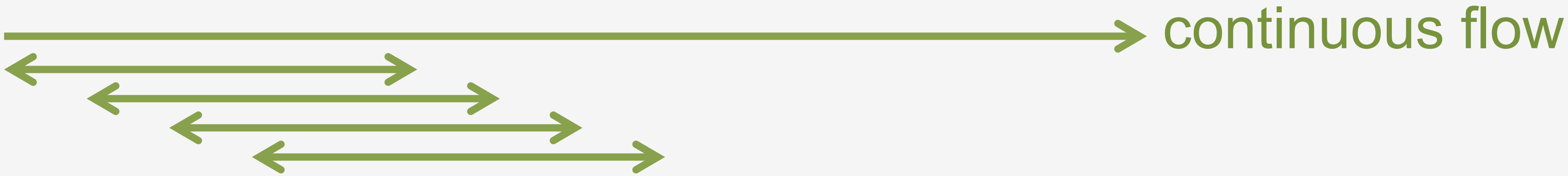
  - fixed size, static encoding window

convolutional codes

- sliding window encoding

NWCRG

  - a fixed size encoding window slides over source symbols



- elastic window encoding

NWCRG

  - a variable size encoding window slides over source symbols

NWCRG activities (non exhaustive list)

- see IRTF meeting proceedings
  - IETF86 http://www.ietf.org/proceedings/86/nwcrg.html
  - IETF87 http://www.ietf.org/proceedings/87/nwcrg.html
  - IETF88 http://www.ietf.org/proceedings/88/nwcrg.html

- some contributions are on RLC codes
  - various results on RLC codes and their application
  - structured RLC codes
  - distributed Reed-Solomon encoding
  - Kodo RLC library (comment: beware of license)
  - *not yet available, but in progress… Addition of RLC support in our http://openfec.org library*

NWCRG activities… (cont')

- others are on transport protocols for NC
  - coded TCP
    - improve TCP goodput by sending encoded symbols
  - TCP-IR (instant recovery)
    - a simple and pragmatic approach to solve some of the problems
  - Tetrys
  - DragonCast

Focus 1: Tetrys “on-the-fly” encoding protocol

(representative of a broader class of solutions)

http://www.ietf.org/proceedings/86/slides/slides-86-nwcrg-1.pdf

http://websites.isae.fr/tetrys/

P.U. Tournoux, E. Lochin, J. Lacan, A. Bouabdallah, V. Roca,
``On-the-fly erasure coding for real-time video applications'',
IEEE Transactions on Multimedia, Vol 13, Issue 4, August 2011.

Tetrys principles

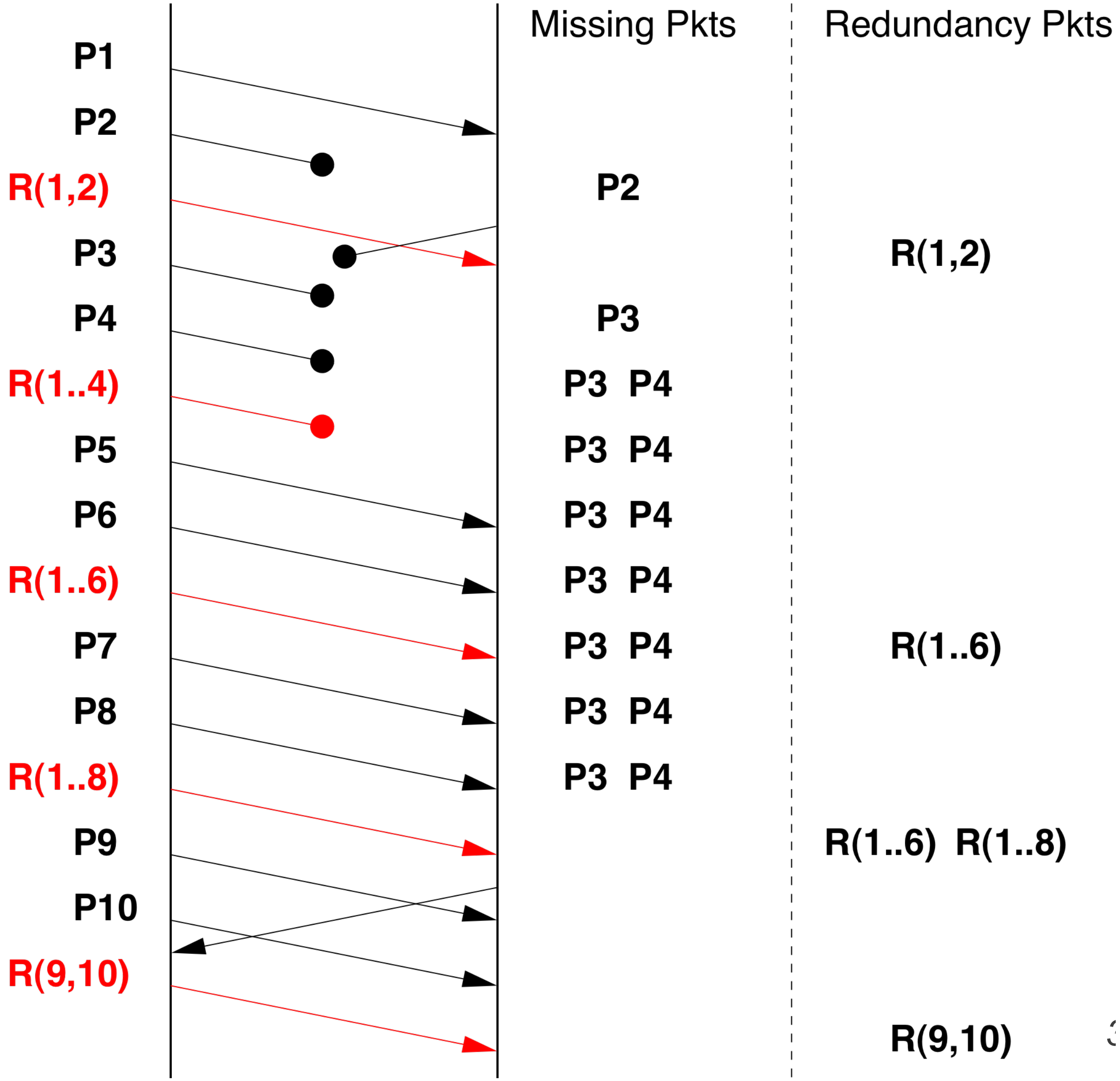
- one technique, several ways to apply it
  - **elastic encoding window** approach

  - **unicast transmission with acknowledgments**
    ⇒ encoding window contains any non-acknowledged packet
  - **key parameter: code rate**

Tetrys principles… (cont')

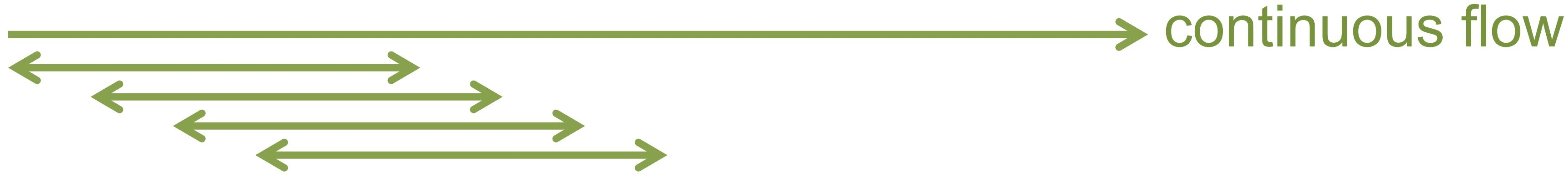
- example: ACKs enable sender to adjust encoding window

code rate 2/3



Tetrys principles… (cont')

- Tetrys can be **turned to a sliding window** (particular case)



  - **useful in case of unicast or multicast flows, without any acknowledgment**

- Tetrys can be used in multi-path environments too

Tran-Thai, Tuan and Lochin, Emmanuel and Lacan, Jérôme
Online multipath convolutional coding for real-time transmission.
19th Int. Packet Video Workshop, May 2012.

Focus 2: Structured RLC codes: why? what for? how?

Motivations

- RLC are naturally random
  - **it's easy, efficient, and flexible**

- but there are incentives to have "structured" codes
  - **sparse codes** are **faster** to encode/decode
    - **an order of magnitude difference, because:**
      - fewer XOR and/or FF symbol operations
      - fast ITerative (IT) decoding works better
  - certain **structures** are extremely **efficient**
    - e.g., LDPC-Staircase [RFC5170] [WiMob13]
    - e.g., irregular LDPC codes perform the best with IT decoding

---

[WiMob13] V. Roca, M. Cunche, C. Thienot, J. Detchart, J. Lacan, ***"RS + LDPC-Staircase Codes for the Erasure Channel: Standards, Usage and Performance"***, IEEE 9th Int. Conf. on Wireless and Mobile Computing, Networking and Communications (WiMob), October 2013. http://hal.inria.fr/hal-00850118/en/

Goals of this work

- design codes that:
  - can be used as **sliding/elastic encoding window** (convolutional) and **block** codes
    - **there are use-cases for each approach**
  - can be used with encoding window/block sizes in **1-10,000s symbols** range
    - **depends on the use-case**
  - can be used as **small-rate** codes
    - **can generate a large number of repair symbols**
      - even if it’s rarely useful

Goals of this work… (cont')

- have excellent erasure recovery **performance**
  - **often a complexity versus performance tradeoff**
  - **it's good to be able to adjust it on a use-case basis**

- enable **fast** encoding and decoding
  - **sender and/or receiver can be an embedded device**

- enable **compact and robust signaling**
  - **transmitting the full encoding vector does not scale**
  - **prefer a function + index to identify the symbols/coefficients**
    - can be a PRNG + seed
    - the function is known to both ends and the key is carried in the packet header

Goals of this work… (cont')

- focus **only** on use-cases that require **end-to-end encoding**
  - "end" means either "host" or "middlebox", it's the same
  - because it simplifies signaling
    - **intermediate node re-encoding requires carrying the full encoding vectors which does not scale!**
  - sure, it's a subset of NWCRG candidate use-cases
    - **but it's well suited to Tetrysand also to FLUTE/ALC and FECFRAME**

Idea 1: mix binary and non-binary

- mix binary and non binary
  - most equations are **sparse** and coefficients **binary**
  - a limited number of columns are **heavy** with non-binary coefficients (e.g., on $GF(2^8)$)

- there are good reasons for that:
  - sparseness is a key for high encoding/decoding speeds
  - density/non binary are good for recovery performances
  - gathering dense coefficients in columns (i.e. to certain symbols) is a key for high speed decoding [WiMob13]

[WiMob13] V. Roca, M. Cunche, C. Thienot, J. Detchart, J. Lacan, ***"RS + LDPC-Staircase Codes for the Erasure Channel: Standards, Usage and Performance"***, IEEE 9th Int. Conf. on Wireless and Mobile Computing, Networking and Communications (WiMob), October 2013. http://hal.inria.fr/hal-00850118/en/

Idea 1: mix bin and non-bin… (cont')

- block code example
  - (sparse + non-bin. columns) only

source symbols $\quad$ repair symbols

$$
\begin{array}{cccccccccccc}
s_0 & s_1 & \ldots & s_{19} & s_{20} & \ldots & s_{39} & r_0 & r_1 & r_2 & \ldots & \\
\end{array}
$$

$$
H = \left[\begin{array}{ccccccccc|ccccc}
1 & 0 & \cdots & 1 & \mathbf{29} & 0 & 0 & \cdots 1 & \mathbf{77} & 1 & & & & \\
0 & 1 & \cdots & 1 & \mathbf{62} & 1 & 0 & \cdots 0 & \mathbf{18} & & 1 & & & \\
 & & & & & & & & & & & 1 & & \\
 & \text{sparse binary part} & & & & \text{sparse binary part} & & & & & & & \ddots & \\
 & & & & & & & & & & & & & 1
\end{array}\right]
$$

$$r_0 = s_0 + \ldots s_{18} + 29^* s_{19} + \ldots s_{38} + 77^* s_{39}$$

dense non-binary columns over $GF(2^8)$

Idea 2: add a structure

- technique 2: add a structure to the right part of H
  - we know that a "staircase" (A.K.A. double diagonal) is highly beneficial…

$$\begin{array}{cc} & \begin{array}{l|l} s_0\ s_1\ \ldots\ldots\ldots\ldots\ldots\ s_{k-1} & r_0\ r_1\ \ldots\ r_{n-k+1} \end{array} \\ H = & \left[\begin{array}{l|l} 0\,1\,0\,0\,1\ \ldots\ldots\ldots\ 0\,0\,1 & 1 \\ 1\,0\,0\,1\,0\ \ldots\ldots\ldots\ 1\,1\,0 & 1\,1 \\ 0\,0\,1\,0\,0\ \ldots\ldots\ldots\ 0\,0\,0 & \;\;1\,1 \\ \quad\ \ \vdots \qquad\qquad\qquad\quad \vdots & \qquad \ddots \\ & \qquad\quad 1\,1 \\ 0\,1\,0\,1\,0\ \ldots\ldots\ldots\ 0\,1\,0 & \qquad\qquad 1\,1 \end{array}\right] \end{array}$$

  - … but when used in convolutional mode, **signaling** turns out to be **prohibitively complex**
    - believe me ;-)

Idea 2: add a structure… (cont')

- so we add a **single heavy row** and make **all repair symbols depend on it**
  - **it's now quite simple, even when used in convolutional mode**
    - several sums will be transmitted (e.g., periodically), and it is sufficient to identify the last symbol of the sum in the signaling header
  - **it's efficient (see later), at the price of extra XOR operations**

r_0 is the heavy repair symbol

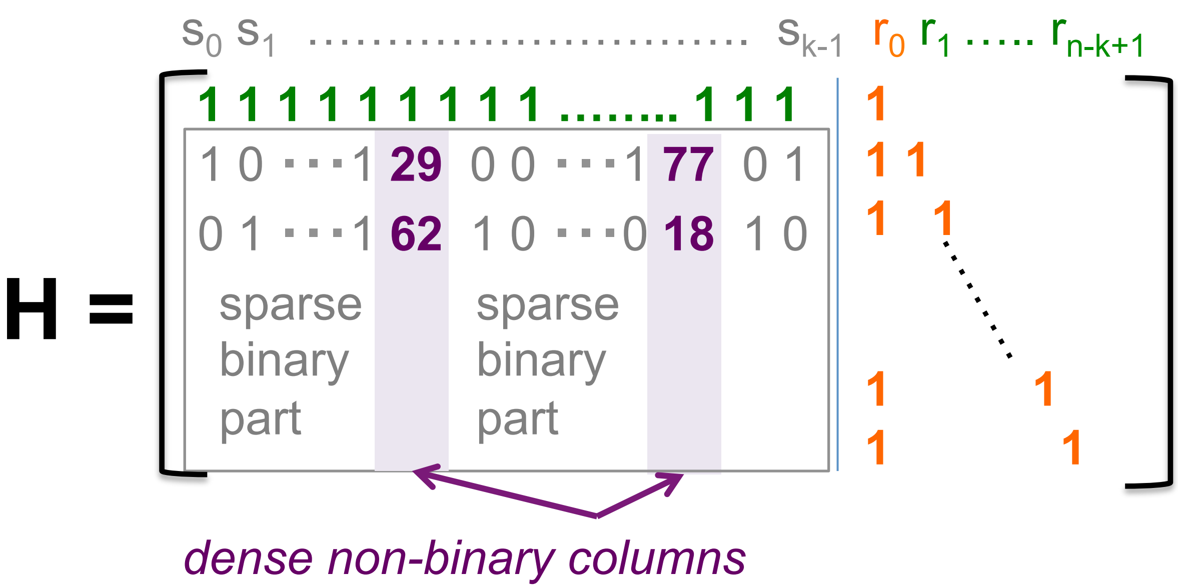
$$
H = \begin{array}{c}
\begin{array}{cccccccccc|cccc}
s_0 & s_1 & \cdots & & & & & s_{k-1} & & & r_0 & r_1 & \cdots & r_{n-k+1}
\end{array} \\
\left[\begin{array}{cccccccccc|cccc}
1 & 1 & 1 & 1 & 1 & \cdots & 1 & 1 & 1 & 1 & 1 & & & \\
1 & 0 & 0 & 1 & 0 & \cdots & & 1 & 1 & 0 & 1 & 1 & & \\
0 & 0 & 1 & 0 & 0 & \cdots & & 0 & 0 & 0 & 1 & & 1 & \\
& \vdots & & & & & & & & \vdots & \vdots & & & \ddots \\
& & & & & & & & & & 1 & & & 1 \\
0 & 1 & 0 & 1 & 0 & \cdots & & 0 & 1 & 0 & 1 & & & & 1
\end{array}\right]
\end{array}
$$

each repair "includes r_0"

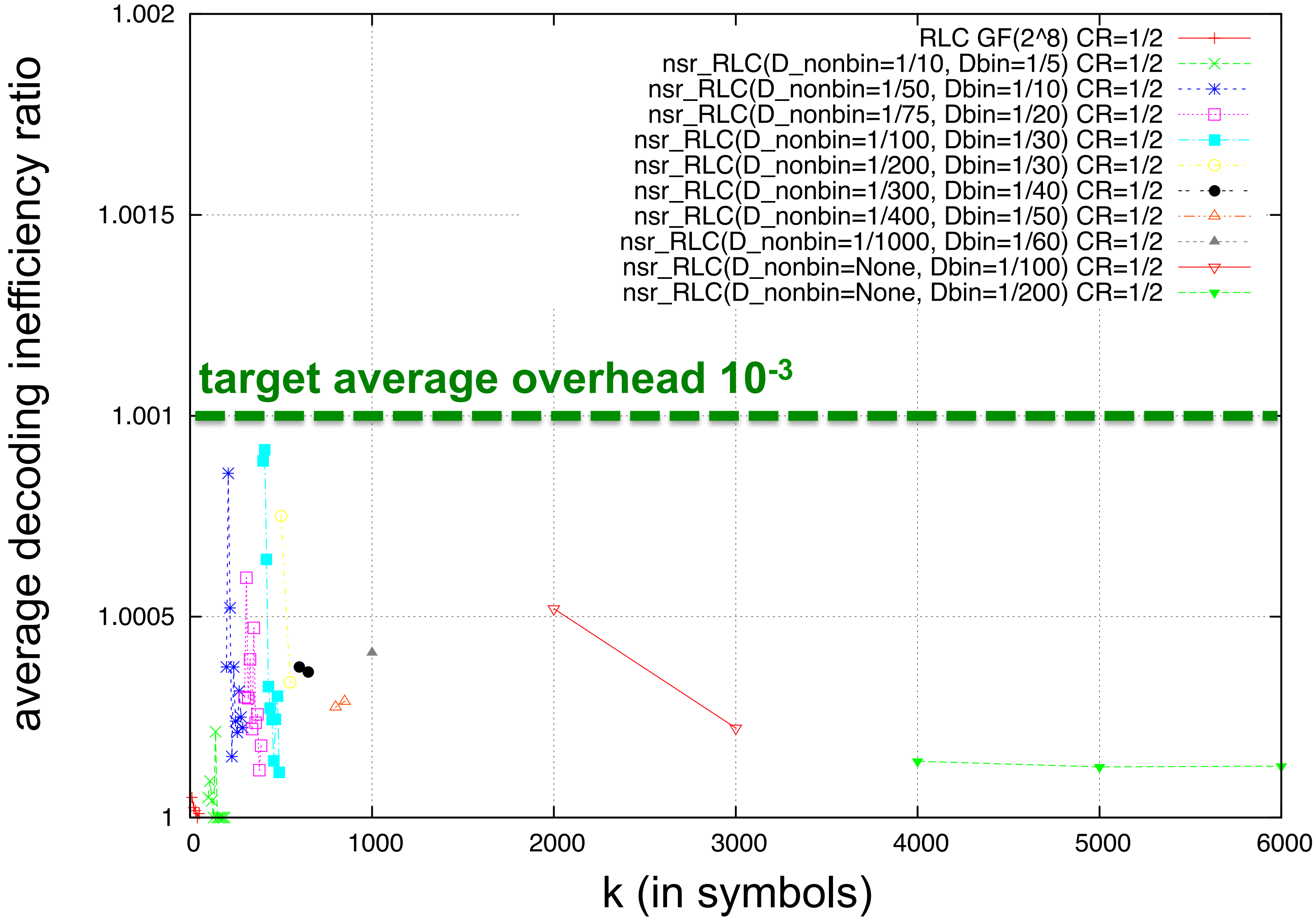
- **NB: other ways to define heavy rows are feasible (e.g., with random coefficients over GF(2^8)…**

Let's put ideas 1 and 2 together

- 3 key parameters
  - k: source block or current encoding window size
  - D_nonbin: controls number of heavy non-binary columns
    - D_nonbin = nb_non-binary_coeffs / k
  - D_bin: controls the density of the sparse sub-matrices
    - D_bin = nb_1_coeffs / total_nb_coeffs_in_binary_submatrix
  - {D_nonbin, D_bin} depend on k and target max. overhead



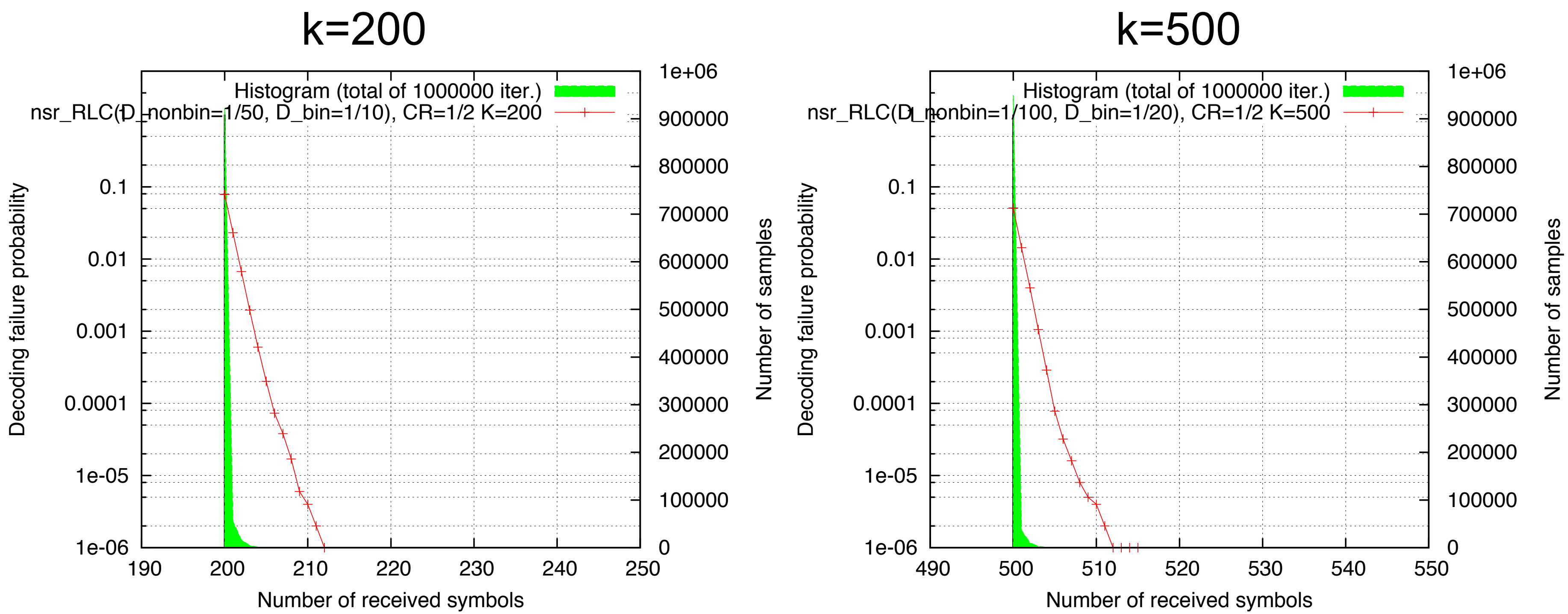
Preliminary results



NB: results are presented here as the concatenation of small curves…
In practice it will be a single curve for a single code…

Two close-ups

- decoding failure probability curves for k=200, 500
  - **no visible error floor at 10^{-6} failure probability, which is excellent ☺**



This is work under progress…

- many key questions remain
  - what are the **performances** when used in sliding or elastic encoding window?
    - e.g. with Tetrys
  - how **fast** is it?
    - e.g., compared to our optimized LDPC-Staircase/RS codecs
  - how does it **scale** with k?
    - e.g., compared to our optimized LDPC-Staircase codec
  - define **signaling** aspects
    - FEC Payload ID (in each packet sent)
    - FEC Object Transmission Information (per object/session)

- want to know more?

  http://www.ietf.org/proceedings/88/slides/slides-88-nwcrg-2.pdf

Conclusions

Conclusions

- there are plenty of opportunities to contribute to IETF/IRTF
  - it's open and academic-friendly
    - **compared to other SDOs**
  - the directions taken by the NWCRG group depend on individuals
    - **there's no a-priori forbidden topics**
      - if it fits within the "Internet" (in its broader meaning), it's okay
    - **but it MUST NOT break the Internet**
      - do not create flows/protocols that do not react in front of congestion signals
      - "TCP friendliness" (to some extent) is unavoidable